National Bureau of Standards

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Sheet-Stringer Panels for Airplane Construction

During flight, the metal covering or "skin" of modern aircraft should satisfy two requirements. It should carry a large part of the load and it should remain aerodynamically "smooth" in order to prevent excessive drag. The sheet, because of its flexibility, shows a tendency to deflect laterally and become wavy under load. Therefore, determination of the load at which transition from a smooth to a wavy, buckled condition of the sheet takes place, and the effect of this buckling on the strength of the aircraft structure, are important problems. A more complete understanding of the behavior of thin sheet in aircraft structures has resulted from structural tests and theoretical investigations carried out at the National Bureau of Standards for the Navy's Bureau of Aeronautics and the National Advisory Committee for Aeronautics.

The thin skin of the airplane is generally divided into rectangular panels by the main spars and ribs. Each panel is bounded by relatively heavy members which form the structural framework of the airplane. The panel itself consists of a piece of sheet with closely spaced stringers welded or riveted to the sheet for reinforcement. The buckling of the sheet between stringers in a panel under end compression, the strain distribution in the sheet as a function of the stringer stress, and the load carried by the sheet, have been considered from a theoretical point of view by a number of authors. However, little experimental confirmation of this theoretical work has been obtained, and even this has been restricted in scope. An experimental study under carefully controlled end conditions was therefore carried out at the Bureau to investigate the effects of stringer spacing, rivet or spot-weld spacing, and sheet thickness, on the load carried by the sheet for 24S–T aluminum-alloy sheet-stringer panels in end compression. It was found that the effect of rivet spacing followed, to a large extent, a theory proposed by W. Lavern Howland and that the effect of stringer spacing could be determined from a theory derived by Karl Marguerre. A nomogram, developed by Bureau scientists on the basis of theory and experimental data, has made it possible to predict the load carried by a buckled sheet at failure.

In the first tests the panels were flat, although in actual airplanes the outer skin must be gradually curved for aerodynamic reasons. In order therefore to determine the effect of curvature, additional tests were conducted on panels covering a range of curvature from flat to 20-inch radius. This effect was shown to depend on the dimensionless ratio b^2/Rt, where b=stringer spacing, R=radius of curvature, and t=sheet thickness. The curvature was found to increase markedly the load at which buckling of the sheet occurred. In one case, with $b^2/Rt=33$, the buckling load was increased 4.35 times. The load carried by the sheet at failure was, however, not appreciably affected by the curvature. It was concluded that curvature would have a beneficial effect in delaying buckling, thereby keeping the skin of the airplane smooth to high loads, but that it could not be expected to increase appreciably the ultimate load.

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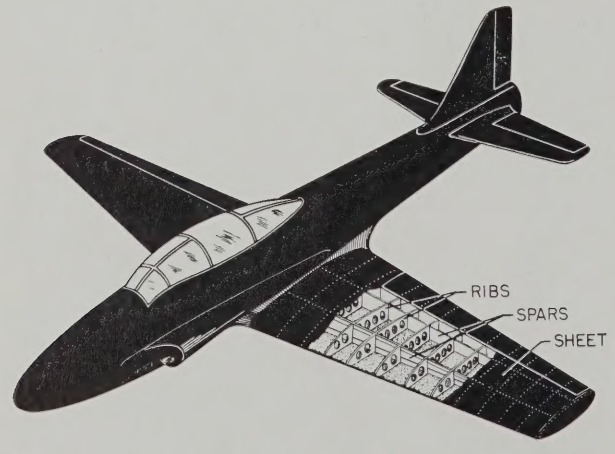
Lateral Loading

The outer skin of the airplane must resist the lateral pressure of the surrounding air as well as loads in its own plane, such as the end-compressive loads. Furthermore, in the case of seaplanes, the bottom plating must withstand severe impact during landing and takeoff, especially on rough water. Under such conditions, pressures as high as 6 lb per sq in. have been measured, while theoretical considerations indicate that much higher pressures are possible. With the advent of high-altitude flying and pressurized cabins, differential pressures as high as 6 lb per sq in. are not uncommon. For these reasons, a series of tests was conducted to determine to what extent lateral pressure affects the ability of sheet-stringer panel construction to withstand the primary axial structural loads. An elaborate technique was required in these tests to prevent the lateral loading devices from restraining axial shortening of the panel. An additional problem arose when laterally loaded panels tended to buckle with a "pop", thus disturbing the sensitive displacement-measuring gages used in the tests. Results of this work indicate that the effect of normal pressure on the behavior of sheet is quite similar to that of curvature. This effect was found to follow the dimensionless ratio pb^4/Et^4, where p=pressure, b=stringer spacing, E=Young's modulus, and t=sheet thickness. Even small pressures caused some increase in the buckling load, while for large pressures the increase was as much as 500 percent in some cases.

An interesting and paradoxical result was found in some of the tests with lateral pressure and axial load. In the presence of lateral pressure, doubling the sheet thickness resulted in a reduction in the buckling stress. This was attributed to the fact that the thinner sheet "dishes" in farther under normal pressure and the stabilizing effect of the "dishing" more than compensates for the reduction in stability due to reduced sheet thickness. Lateral pressure on sheet-stringer panels was found to have little effect on the load carried by the sheet at failure and to cause a small reduction in the load carried by the stringers.



The skin of an airplane is divided into rectangular panels by the primary structural framework of ribs and spars. The sheet-stringer panel is a basic structural element in semimonocoque airplane construction.

Analysis of Sheet Stresses

Paralleling the experimental investigations of the sheet-stringer panels, an attempt was made to obtain a rational analysis for the stresses in sheet as loaded in aircraft structures. The analysis was complicated by the fact that the deflections of the sheet may be comparable in magnitude with the sheet thickness. In such cases, the classical linear-plate theory of Kirchoff may yield results that are considerably in error, and a more rigorous theory that takes account of deformations in the middle surface should be applied. The fundamental nonlinear large-deflection equations for the more exact theory were derived by von Kármán 38 years ago. Using the test results as a guide in the choice of a suitable series expansion for the lateral deflection of the sheet, a solution of von Kármán's equations was obtained in terms of trigonometric series. Numerical results were computed for the effect of axial load, lateral pressure, curvature, and shear on the stress distribution in the elastic range for a variety of rectangular plates typical of aircraft construction. The computed results were compared with experimental results wherever they were available and found to be in excellent agreement.

Instability of Stringers

The tests that have been described were primarily directed toward a better understanding of the relation-

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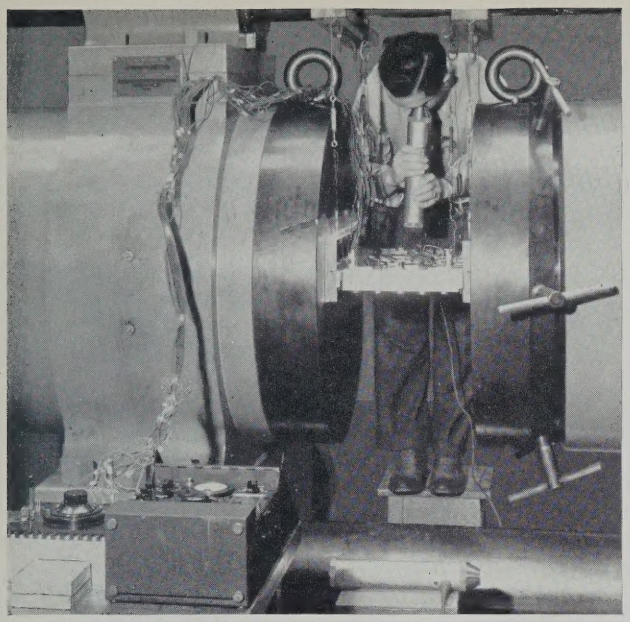
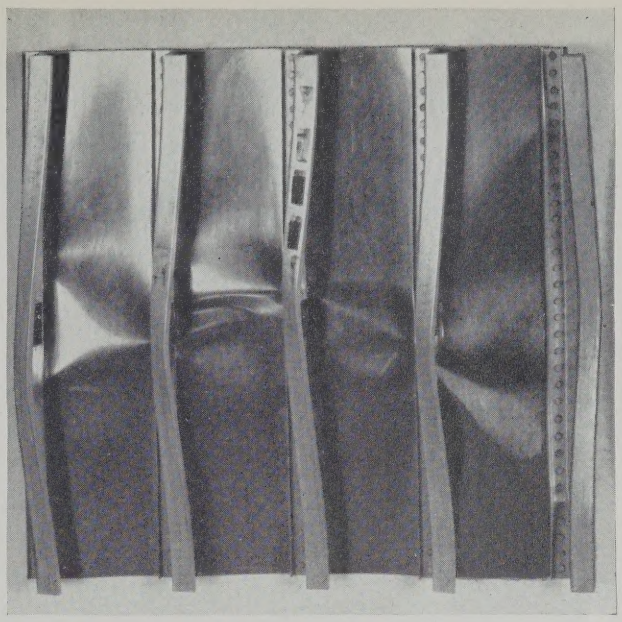




Behavior of the wing surface of an airplane under load is studied by subjecting a panel of the sheet to compressive loads (left) in one of the Bureau's testing machines. Tuckerman optical strain gages and SR–4 wire strain gages are used to measure the deformation of the panel under load. Failure of panels reinforced by relatively thin stringers of open cross-section (right) is characterized by combined twisting and bending of the stringers.

ship between buckling of thin sheet and its ability to carry axial load. Of equal importance, however, is the instability of the stringers used to reinforce the thin sheet. These reinforcements, if relatively thick as in steel bridges or buildings, have instabilities of the Euler-column type in which only bending takes place. However, when the reinforcements are relatively thin and of open cross-section, as is frequently the case in aircraft structures, the instability becomes more complicated and involves both torsion and bending. A general theory for this type of instability of stringers, when not attached to sheet, was developed by Robert Kappus in 1937. To check the validity of this theory, tests were made at the Bureau on 125 column specimens of reinforcements typical of aircraft. When used together with formulas that take plastic yielding of the material into account, Kappus' theory gave good agreement with experimental results.

The success of Kappus' theory in explaining the instability of stringers not attached to sheet suggested its use also for stringers attached to sheet as in conventional sheet-stringer airplane construction. The theory was extended to take into account the restraint the sheet provides against warping and twisting of the stringer. A set of panels using stringers of Z-cross-section was constructed and subjected to axial compression tests involving extensive measurements of the deformations of the stringers near the failing load. The extended theory was compared with the experimental results obtained at the Bureau and at other laboratories. For relatively heavy stringers (ratio of stringer thickness to sheet thickness of two or more), this theory yielded reliable values of the maximum load. For panels with relatively light stringers (ratio of stringer thickness to sheet thickness of one or less), the computed loads agreed with experimental values in many cases but not in all; when agreement was lacking, the computed values were always high. The high values are attributed to the fact that neither Kappus' theory nor the extended theory takes adequate account of the distortion of the stringer cross-section which has been observed in some panels with relatively light stringers. A rational theory for the failure of stringers of this type is still not available.

Open-section stringers have been widely used in sheet-stringer construction. One reason for preferring them to closed "hat-section" stringers has been that they can be attached with a single row of rivets. This reduces the cost of fabrication and makes it easier to inspect the riveted structure. Although closed-section stringers are more stable, it was possible to obtain open-section stringer configurations with aluminum alloy of moderate strength such as 24S–T that would be stable up to the yield strength of the material. With the advent of alloys such as 75S–T, which have a much higher yield strength, the greater stability of closed-section "hat" stringers makes their use preferable. The trend in airplane construction toward high-strength alloys has resulted in an increasing use of "hat-type" stringers for reinforcing the sheet and, in some cases, double-skin "sandwich-type" constructions in which corrugations or spacers are used to separate the two sheets. Current investigations of sheet-stringer construction are being directed primarily toward the fundamental mechanism of failure of such panels.

Effect of rivet and spot-weld spacing on the strength of axially loaded sheet-stringer panels, Samuel Levy, Albert E. McPherson, and Walter Ramberg, NACA Tech. Note No. 856 (1942).

Effect of curvature on strength of axially loaded sheet-stringer panels, Walter Ramberg, Samuel Levy, and Kenneth L. Fienup, NACA Tech. Note No. 944 (1944).

Landing of seaplanes, Herbert Wagner, T. M. No. 622, NACA (1931).

Effect of normal pressure on strength of axially loaded sheet-stringer panels, A. E. McPherson, Samuel Levy, and George Zibritosky, NACA Tech. Note No. 1041 (1946).

Instability of extrusions under compressive loads, Walter Ramberg and Samuel Levy, Jour. of the Aero. Sci. Vol. 12, No. 4, p. 485 (1945).

Description of stress-strain curves by three parameters, Walter Ramberg and William R. Osgood, NACA Tech. Note No. 902 (1943).

Properties and Use of Eye-Protective Glasses

In keeping with general industrial progress in this country, protective glasses and goggles have been developed and improved until today there is a glass or goggle available for adequate protection in every occupation and avocation. Recently, an investigation was made at the Bureau covering the spectral-transmissive properties of about 200 glasses intended for use as sun glasses or for special industrial operations where injurious amounts of ultraviolet, luminous, or infrared radiant energy are present.[1] Extensive consideration was given to the elimination of glare, the distortion of colors of objects, the use of glasses for driving at night, the standardization of glasses for out-of-doors and industrial purposes, and the spectral-transmissive properties of glasses for use under various types and intensities of radiant energy.

Conservation of eyesight is one of the foremost problems that confront safety engineers in America today. The eyes must be protected not only from mechanical injury, but from exposure to various sources of radiant energy. The natural protective mechanism of the eye is sufficient to adapt it to ordinary amounts of radiant energy encountered about the home, office, shop, or other place of business or recreation. However, in certain outdoor activities, for example, automobile driving and snow or water sports, and in industrial applications such as in steel mills, electric or gas welding, and around furnaces, glasses having low transmittance to harmful radiant energy are required.

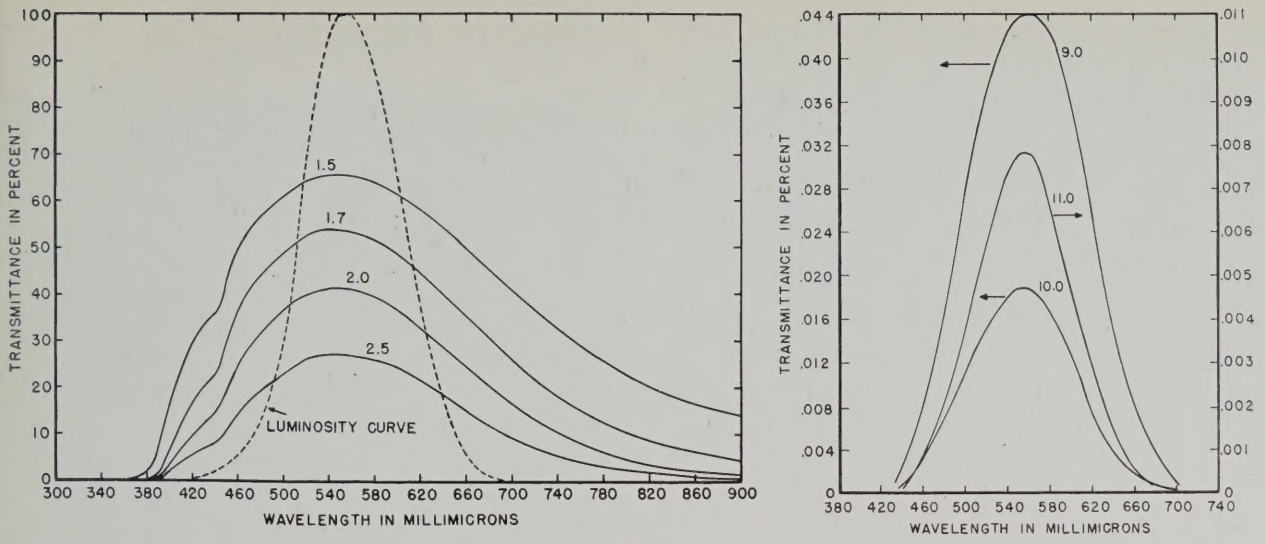
The principal reason for which most people wear dark glasses is to eliminate or reduce glare in connection with ordinary outdoor activities. Everyone, no doubt, has experienced the temporary blurring of vision, eye fatigue, or other unpleasant sensation caused by an excessive brightness-glare within the field of vision. The wearing of dark glasses simply reduces the brightness to a comfortable value such that the protective mechanism of the eye can assume complete control of the radiant energy reaching the retina. This result may be achieved through neutral, amethyst, red, amber, yellow, green, blue, or combination-color glasses so long as the optical density (shade number) is sufficient to reduce the luminous transmittance to the proper value for the light intensity encountered.

[1] A comprehensive report of this work is being published as National Bureau of Standards Circular C471.

Glasses having sufficient opacity to give the eye reasonable protection from glare usually exhibit a considerable amount of selective absorbance and may appreciably alter the color of objects. The neutral-shade and smoked glasses have a roughly uniform absorbance throughout the visible spectrum and consequently cause the least distortion of color. On the other hand, since the maximum of visual response for wear outdoors is in the yellow-green, glasses having a hue in the yellow-green or greenish-yellow portion of the visible spectrum are finding favor in aviation, automobile driving, and recreation. The slight distortion in object color appears to be of less importance than the gains obtained through elimination of radiant energy that serves no useful purpose.

Because of the serious risks involved, the use of dark glasses for relieving glare in night driving demands special attention. Most types or combinations of shaded glasses have been found to be unsafe as a means of protection against glare from automobile headlights.

Industrial applications of eye-protective glasses include numerous welding and cutting activities such as this operation in the Bureau's welding shop. The operator's eyes are protected from the high radiant flux by a glass containing didymium.



Spectral transmittance curves of light-shade welding glasses (left) are compared with the luminosity curve of the human eye (dotted line). Such glasses are useful for protection from the glare of sunlight and from stray radiant energy around such industrial operations as cutting, welding, metal pouring, and furnace work. The operator in these activities, however, uses darker-shade glasses (curves, right) to protect the eyes from harmful ultraviolet and infrared rays. Note the complete opacity of these glasses to ultraviolet radiant energy and the negligible transmittance of the infrared. Numbers beside the curves are shade numbers.

In general it is the belief that any advantage of reducing glare from automobile headlights by wearing dark glasses is more than counterbalanced by the extra hazard arising from the decreased visibility of objects. Tests by a number of observers indicate, however, some basis for claims of increased visibility and reduction of glare through the use of a yellow glass.

Present-day welding glasses having high opacity for the ultraviolet and infrared regions of the spectrum insure complete protection of the eyes when working with any source of radiant energy encountered in industry, provided the proper shade number for clear sight is employed. Since there are differences between individuals, the exact shade number for a particular operation must be chosen through trial by the operator himself for best results in his work.

In operations such as welding with coated rods, or in aluminum or magnesium welding and cutting, where high radiant flux is produced at the wavelengths of the sodium lines, glasses containing didymium (and sometimes additional materials to absorb more completely the red end of the spectrum) have been found very useful.

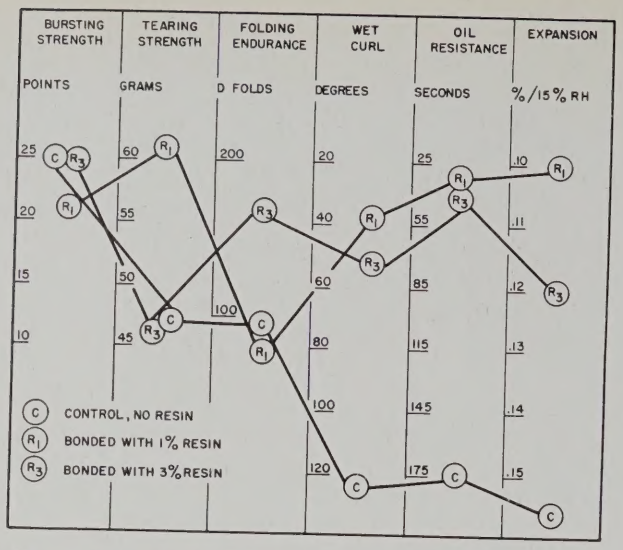
Special cobalt-blue glasses have been used and demanded by operators of open-hearth furnaces and similar installations, in the particular shade with which the operator is familiar, because of the contrast in brightness that is obtained between the molten metal and the interior of the furnace. In the production of steel and cast iron by the Bessemer process, a blue-amber glass is employed by the operator to estimate certain color changes of the flame as the impurities are burned off. When each impurity (primarily silicon, magnesium, and carbon) burns as the result of an air blast through the molten metal, a distinctive color appears, on which the operator depends in determining the proper point at which to stop the "blow" and to pour the metal.

Ordinary glass, with its high sodium content, gives off an intense yellow flare when heated. Because of this bright light (at 589.3 millimicrons) the glass worker has difficulty in seeing, without special glasses, the glass to bend or shape it into the desired article. It has therefore become the practice of glass blowers to wear didymium glasses which have a high total luminous transmittance and at the same time a high absorptance at 589.3 millimicrons.

When glasses having a high optical density are worn for protection of the eyes in industrial operations the elimination of harmful ultraviolet rays must be given first attention. The infrared rays are given second consideration because, their action being thermal, the worker is generally forewarned by a burning sensation. Finally the optical density, or shade number, determines the suitability of a glass for a particular operation.

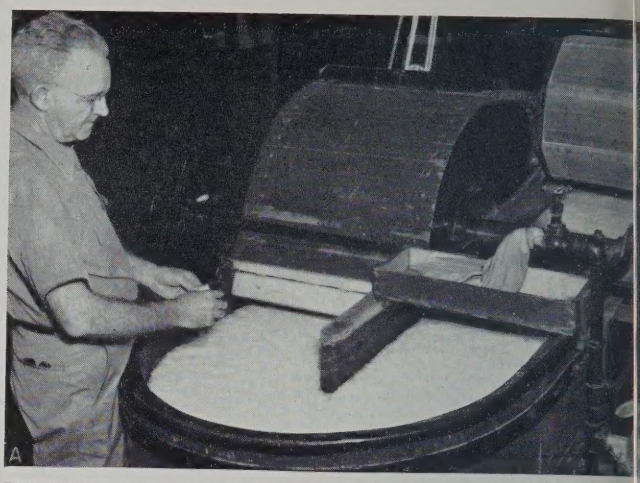
Through accurate determination of the spectral transmittances and application of luminosity factors for a complete radiator (black body) at a color temperature of 2848° K, standards of optical density have been set up in the form of samples of welding glass having luminous transmittances near the minimum and maximum densities for the various shades.

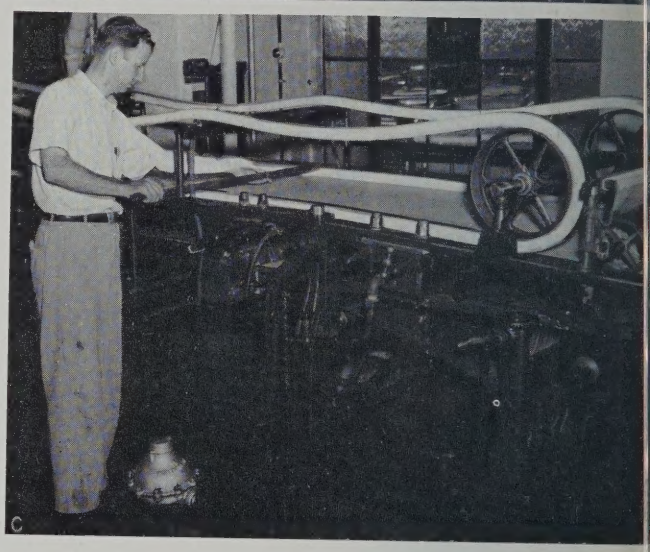
As a result of the Bureau's investigation it has been proposed that sun glasses be grouped into three or four shades, A, B, C, and D, having luminous transmittances of 60, 35, 25, and about 10 percent respectively, values that correspond roughly with those for the industrial shades No. 1.5, 2.0, 2.5, and 3.0.



Advantages of resin-bonding as against gel-binding, or hydration, are evident in a comparison of three papers consisting of 75% sulphite and 25% soda, developed by: (C) 9½ hours of beating, no resin; (R_1) 5½ hours beating plus 1% resin; (R_3) 1½ hours beating plus 3% resin.

Resin Bonding—A New





High strength and superior dimensional stability are among experimental paper mill, stock is prepared in the beater (A when made into paper. Synthetic resins are added (B) jus screen of the paper machine (C). Most of the water is re progressively through the steam-heated rollers of the drye which the degree of smoothness and density is controlled h

Through the use of a synthetic resin which imparts unusual strength to paper, vast amounts of wood which have been of little value in the production of paper can now be added to the nation's critical supply of satisfactory pulp timber. This new technique in paper making combines superior dimensional stability with high strength, when using the ordinary commercial wood pulps, and also makes it possible to produce suitable papers from relatively abundant wood species not now fully utilized. The development, growing out of a comprehensive research program at the National Bureau of Standards on offset printing papers,[2] thus points to improved products and the conservation and extension of critical raw material supplies. Furthermore, it does not involve either appreciable increase in costs or any important change in manufacturing methods.

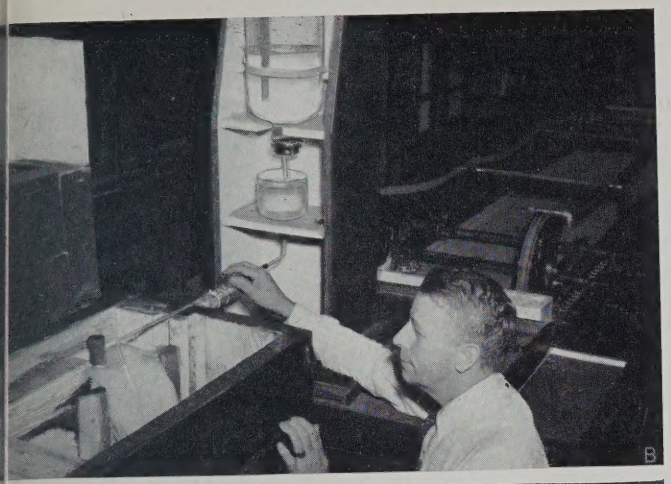
Deciduous woods such as the maple, beech, birch, or poplar have until now been used only as "filler" in the manufacture of high grade printing paper. In 1946, for example, wood of this type accounted for only 16 percent of the pulp consumed and in inventory. No matter how desirable their other characteristics may be, the deciduous woods do not produce the primary qualities of strength and resistance to surface pick, in the usual methods of processing. The development of strength through the use of the synthetic resin, melamine formaldehyde, will have the effect of materially increasing the use of the short-fibered pulps.

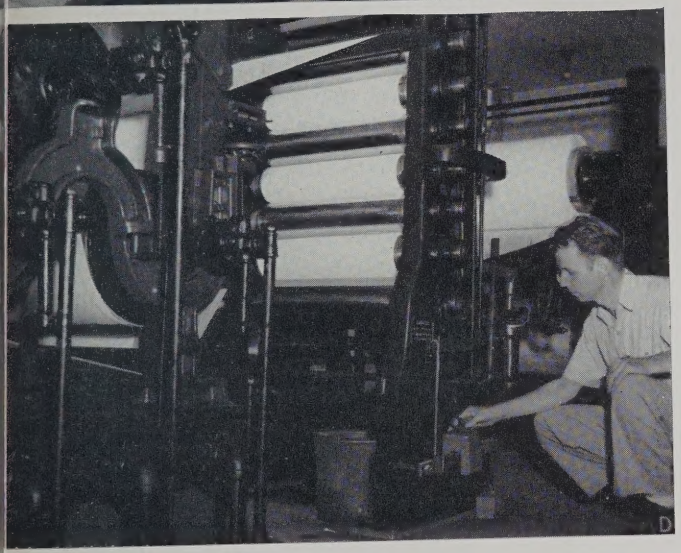
Paper is a felted sheeting of vegetable fibers, formed on a screen from a water suspension of the fibers. In conventional paper making, the fibers are prepared for fabrication by mechanical beating in water. Beating causes the fibers to absorb water and form a gel-like film on their surfaces by a structural change called "hydration." This gel is the cement that bonds the fibers together to give paper of conventional manufacture its strength. Although this beating process has been necessary to provide sufficient fiber bonding for certain printing requirements, it also promotes some of the most troublesome behavior of paper in printing, namely, high expansion, excessive curling, slow oil absorption, and show-through of images.

The new technique consists essentially in substituting synthetic resin bonds between the fibers for the gel-like

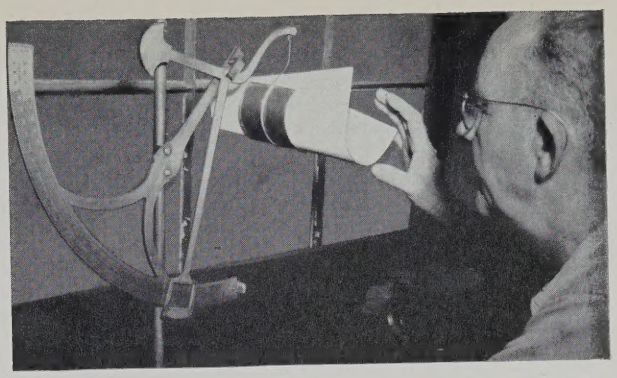
[2] For further technical details, see Resin bonding and strength development in offset papers, by Charles G. Weber, Merle B. Shaw, Martin J. O'Leary, and Joshua Missimer, J. Research NBS **40**, 427 (1948) RP1887.

lopment in Paper Making





roperties imparted to paper by resin bonding. In the Bureau's e the fibers are thoroughly separated so that they will enmesh e the paper stock flows onto the finely woven, continuous wire here by gravity, suction, and pressure. The paper then passes on (D, left) and through the calender section (D, center) in sure applied through weighted levers.



Accurate control of the finished paper is attained by weighing a single sheet on a specially designed scale that indicates directly the basis weight, that is, the weight of the corresponding full ream of sheets.

bonds formed by hydration. The resin bonding gives optimum strength with only a fraction of the beating required to develop comparable strength by beating alone, and produces a superior paper by elimination of the adverse effects of hydration. It is this feature of resin bonding that makes possible the satisfactory sheet strength from pulps of the deciduous woods that do not lend themselves to hydration. Resin bonding thus opens up an entirely new reservoir of fibrous raw material.

Since paper was invented by the Chinese nearly 2,000 years ago, there has been an almost unceasing search for fibrous raw materials. The use of wood, introduced some 75 years ago, brought a breathing spell after periods of near fiber famine. Under the present-day demand, however, the available supply is running low. The magnitude of the fiber requirements for paper can be visualized roughly from the startling fact that all of the cotton grown in the world would not make one-quarter of the paper used in the United States.

In 1944, the Bureau's Paper Laboratory developed a high wet-strength paper primarily for war maps, but made from conventional pulps. The unusual strength was acquired by substitution of resin bonding for the usual gel-like bonds occurring naturally during manufacture. The present development, involving experimental manufacture on a semicommercial scale, is essentially an extension of this work to the short-fibered pulps that possess every characteristic needed for good paper making except the important one of strength. Widely different combinations of commercial wood pulps were investigated to determine the advantages of resin bonding in printing papers. A series of papers was made from each combination with controlled variations in beating, with and without synthetic-resin bonding. In all instances, the resin-bonded papers were superior with respect to curling, oil absorption, folding endurance, resistance to surface pick, and expansivity. Several types of synthetic resins have been used, with melamine-formaldehyde resin giving the best results to date. Surprisingly small amounts of this resin are required, usually less than 3 percent by weight.

Resin bonding as a means of utilizing the deciduous woods is being further explored through the use of experimental pulps made specifically for these investigations by the Forest Products Laboratory of the U. S. Forest Service. Included in the species are aspen, paper birch, and black gum. Pulps for this research have been prepared by various chemical processes and by mechanical grinding. Sulfite-cooked birch and sulfate-cooked aspen pulps have produced excellent printing papers with the aid of resin bonding, whereas they can be used only in small amounts as fillers by conventional processing. These particular woods are

among the most neglected in so far as paper making is concerned.

Some specific accomplishments with melamine-resin bonding are of interest. For normal commercial fiber combinations, it was possible to develop as much strength with 2 percent of resin and no beating as with 9½ hours of beating without resin. Far better strength and resistance to surface picking were obtained with 3 percent of resin than could be achieved by hydration alone, even with the most drastic beating. Moreover, well-beaten papers were unsuitable for printing stock. In the use of deciduous-wood fibers such as birch sulfite and aspen sulfate, the addition of 1 to 3 percent of melamine-formaldehyde resin increased the resistance to surface picking and folding endurance more than 10 times in some instances. Surface fibers must resist the pull necessary to transfer tacky ink from the rubber blanket to the paper without lifting or being themselves transferred to the blanket. A fiber or bundle of fibers loosened by the pull of the ink not only leaves a blemish in the printed image on the sheet where the "picking" occurs, but it may cling to the blanket where it becomes moistened and repels ink so that it prints white spots on succeeding sheets.

All of the resin-bonded papers showed low expansivity, essential, for example, in the printing of maps which may be run through the press as many as fifteen times. Expansivity was measured not only mechanically but in a series of printing tests using six colors.

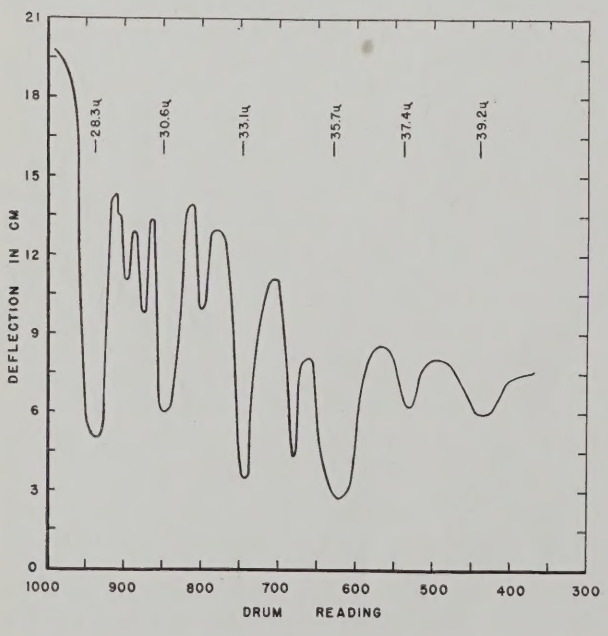
An increase in the use of the short-fibered woods would have its most marked effect in the northeastern region of the United States. In this section, especially, the short-fibered woods have been increasing because past emphasis has always been on the use of the conifers, leaving behind the deciduous woods in logging operations. The ratio of conifers to other types has decreased to the point where the elimination of the short-fibered trees has actually become a problem in forest management.

With the United States using more paper than ever before in its history and the wood pile getting smaller, this new method should aid in making larger stocks available and provide another economic use for the nonconiferous trees. With no large new fiber sources available, the conservation and extension of our fiber resources becomes a matter of serious concern to all.

New Crystals for Infrared Spectrometry

For the past 2 years Bureau scientists have been engaged in a study of the thallium halide crystals to determine the feasibility of developing prisms of these substances for use in long-wavelength infrared spectrometry. While it has been known for some time that such materials possess optical properties of value for measurements in the infrared region, crystals of sufficient size for this purpose had never been produced.

During the recent war, mixed crystals of thallium bromide-iodide (generally referred to as KRS–5) were grown at Jena, Germany, and lenses were actually made from this material for use in field instruments. Early in 1946, under the direction of Dr. Francis Phelps, the Bureau began a program of growing crystals of the thallium halides, and a single mixed crystal of high purity was successfully grown. This crystal, which contained about 42 percent thallium bromide and 58 percent thallium iodide, was large enough for making a prism for use in an infrared spectrometer.



A typical calibration curve of the thallium bromide-iodide prism in an infrared spectrometer is determined from absorption lines of the water-vapor molecule, whose positions are known from grating measurements.

Crystals of the thallium halides are soft and semiplastic, so that only slight pressures will set up considerable internal strains; hence, great precaution must be taken in annealing, cutting, and polishing. Edgar Robertson of the Bureau's Optical Shop succeeded in developing methods for grinding and polishing such crystals. He is now able to produce prism faces that are flat to within a few fringes of yellow monochromatic light. The prism which was made for use in the spectrometer has faces 1¾ by 2½ inches. Because of the high index of refraction, it was cut so that the refracting angle is 26 degrees.

Measurements of the index of refraction of this prism have been made throughout the spectral region extending from the yellow mercury lines in the visible out to 39.2 microns in the infrared, by L. W. Tilton and R. E. Stevens of the optical instruments laboratory and E. K. Plyler of the radiometry laboratory. In the visible region, the value is approximately 2.6, while at 39.2 microns it is about 2.2. Changes in the index with temperature are large, so that constant tempera-

ture control is necessary in carrying out accurate spectroscopic work with this material.

Although prisms of other materials, such as potassium bromide, have been available for measurements to 24 microns, the new thallium bromide-iodide prism now allows observations to be made with a prism spectrometer all the way out to 40 microns. Making use of this prism in an infrared spectrometer, the radiometry laboratory is investigating the transmission of a great variety of materials from 24 to 40 microns.[3] It has been found that many compounds containing atoms of chlorine, bromine, and sulfur have bands in this region. Studies are also being made of the transmission of various solids to find materials having transmission characteristics that would make them suitable window materials for use in cells and in other applications in the 24- to 40-micron band. For example, it has been determined that thin layers of polystyrene and of polyethylene are very transparent out to wavelengths of 40 microns.

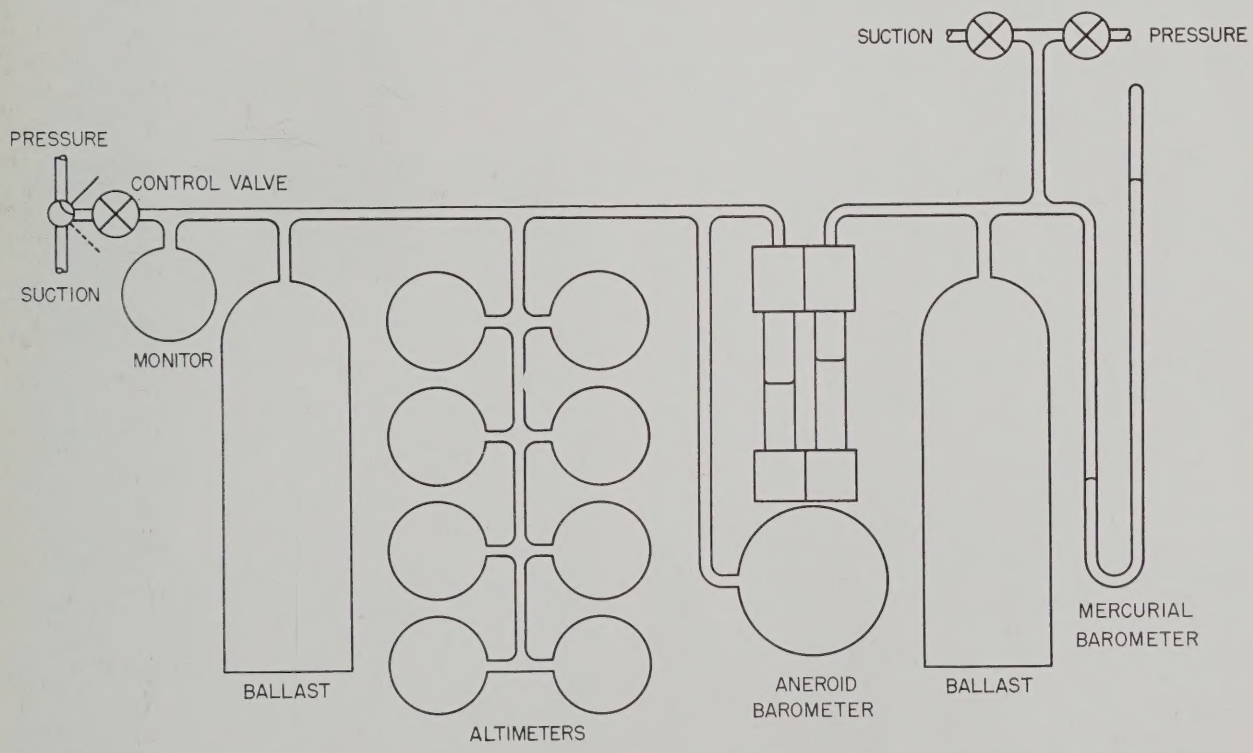
Data obtained in this investigation will be of material assistance in designing lens systems and in determining optimum prism angles for use in the different regions of the infrared spectrum. Other applications of measurements in this portion of the spectrum, such as chemical analysis by infrared methods, have also been worked out as a result of this work. Additional crystals of thallium bromide-iodide of the same high purity have been successfully produced in the Bureau laboratories.

[3] For further technical details, see Infrared prism spectrometry from 24 to 40 microns, by Earle K. Plyler, J. Research NBS **41**, 125 (1948) RP1911.

Altimeter Lag in Simulated Dives and Climbs

Accurate pressure altitudes are often necessary during dives and climbs of aircraft, and other maneuvers in which the altitude changes rapidly. The sensitive altimeters used to make this measurement are ordinarily calibrated "statically," that is, by holding constant the selected absolute pressure while readings are made both on them and on the standard instrument. A "dynamic" calibration, on the other hand, is one in which all readings are made instantaneously while the pressures are changing. This type of calibration is essential for accuracy under dynamic conditions of use as exemplified by high-speed dives or the rapid-climb rates possible with jet planes.

Because the special apparatus and procedures required have not been available, the performance of the altimeter itself has been based on data obtained through



The Bureau's dynamic method of calibrating altimeters, under conditions of rapidly changing pressures that simulate dives and climbs, consists of photographing, simultaneously and at definite short-time intervals, the readings of the altimeters under test and the liquid levels in a manometer that measures the difference between the rapidly changing pressure and the substantially constant pressure maintained in a large ballast tank.

TABLE 1. *Dynamic lag of sensitive altimeters and aneroid barometers in 18,500-foot pressure altitude cycle*

a=observations at 4200 to 5200 feet, b=observations at 8200 to 9200 feet

Instrument	Range	Static hysteresis		Average 1000 ft/min		Average 30,000 ft/min		Maximum 30,000 ft/min	
		a	b	a	b	a	b	a	b
	1,000 ft	*ft*	*ft*	*ft*	*ft*	*ft*	*ft*	*ft*	*ft*
No. 839	35	46	46	11	15	26	29	37	39
No. 840	35	23	16	16	17	40	59	67	80
No. 5373	50	53	64	26	26	46	54	74	71
No. 5374	50	77	93	29	18	71	82	102	124
No. 5375	50	50	53	8	6	40	30	53	45
No. 5384	35	27	28	7	10	25	32	37	40
No. 5385	35	26	23	12	14	34	35	51	43
No. 5386	35	27	29	14	13	30	41	50	58
K-aneroid, 0 to 800 mm Hg		31	35	4	8	6	12	28	19
W&T-aneroid, 20 to 1060 mb		32	40	4	7	[1] 16	[1] 20	[1] 26	[1] 22

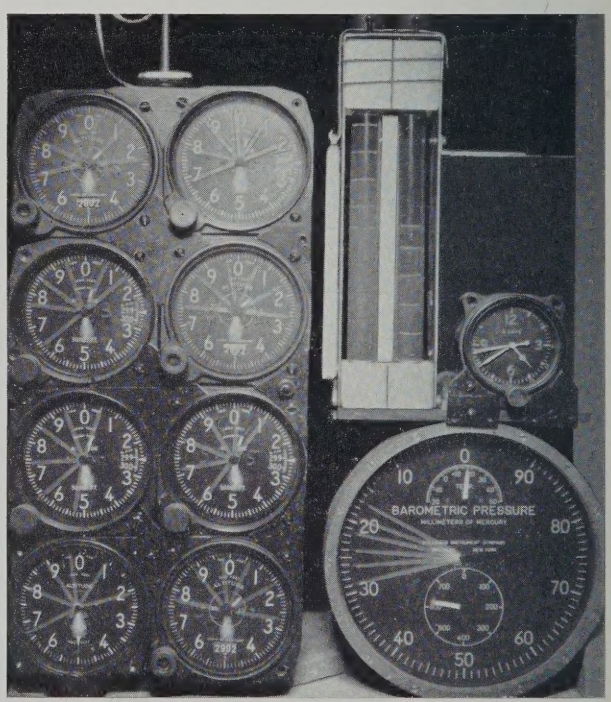
[1] 20,000 ft/min.

indirect methods of analysis and has therefore been the subject of some speculation. This situation has been effectively clarified by an accurate dynamic method [4] of calibration of altimeters developed by Dr. Daniel P. Johnson of the National Bureau of Standards under the sponsorship of the National Advisory Committee for Aeronautics. In connection with this work Dr. Johnson has determined the dynamic lag—the difference between the altimeter reading at a given pressure when calibrated statically and dynamically—for a number of sensitive aircraft altimeters and other aneroid barometers. Results of this investigation indicate that, from the standpoint of efficiency, production tests should be directed toward selecting instruments of relatively low lag rather than attempting detailed measurements of the lag in erratic instruments.

The method of determining the dynamic corrections near any given test point consists essentially in photographing, at definite short-time intervals, the readings of the altimeters under test and the liquid levels in a manometer which measures the difference between the rapidly changing pressure to which the altimeters are subjected and the substantially constant pressure maintained in a large ballast tank. Rates of climb or descent are determined from the time interval and the change of reading between successive observations. The absolute pressure in the ballast volume is obtained by readings on the standard mercurial barometer.

In the arrangement of the apparatus for dynamic calibration, the instruments under test are connected by a manifold to a ballast volume, to one leg of the check-valve manometer, and to the valve by which the rate of pressure change is controlled. The right leg of the check-valve manometer is connected to a second ballast volume, to the standard mercurial barometer, and to the valves for pressure control. The check-valve manometer, the instruments under test, a clock, and a thermometer are grouped in the field of view of a camera, and illuminated by stroboscopic lights.

In operation, the part of the system containing the mercurial barometer is maintained at a constant pressure, near which dynamic observations are desired. The instruments may be carried through the desired sequence of pressure changes without disturbing the set pressure. Photographs are taken at convenient time intervals when the pressure applied to the instruments comes within range of the set pressure plus or minus the indication of the check-valve manometer. This manometer is the U-tube type, fitted with hollow glass-



[4] Calibration of altimeters under pressure conditions simulating dives and climbs. Daniel P. Johnson. NACA Tech. Note No. 1562 (1948).

By means of stroboscopic lights, multiple images of altimeters, manometer, clock, and thermometer are secured on a single film, at pressures near the set point, while the prssure is changing rapidly.

ball check valves which float on the manometer liquid (normal butyl phthalate) to prevent liquid entering the lines during periods of overpressure. Corrections are made for its lag in indication.

The camera shutter is left open during a test run while stroboscopic lights for illuminating the instruments are flashed at equal time intervals controlled by a specially constructed relaxation oscillator. In this manner multiple images are secured on a single film, at pressures near the set point, while the pressure is changing.

Data have been obtained under conditions that are equivalent to rates of change of pressure altitude up to 30,000 feet per minute. Measurements with the apparatus may be extended, however, to 50,000 feet per minute.

In order that all instruments will have comparable pressure exposure prior to test, they should be put into a "cyclic" state. For this particular investigation the instruments were subjected, while being constantly vibrated, to six cycles of pressure change covering the entire range of the test.

The dynamic lag manifests itself as an increase in the hysteresis; that is, the difference, at the same pressure in a pressure cycle, of the instrument readings for pressures increasing and decreasing. The increase is approximately symmetrical, so that adding twice the dynamic lag to the static hysteresis gives the dynamic hysteresis. The dynamic lag is such that the altimeter reads high on descent and low on ascent.

The better 35,000-foot altimeters will probably have dynamic lags of about 5 to 10 feet at low rates (below 3,000 feet per minute), and 20 to 30 feet at 30,000 feet per minute. The lags are somewhat greater and more erratic for 50,000-foot altimeters. Low lags were noted among the large diameter aneroid barometers because there is relatively little friction. Large and irregular lags appear to be associated with large values of the pointer friction. This irregular and erratic lag for a given altimeter was found to vary with readings. As to accuracy, the dynamic calibrations compare favorably with the conventional static calibration, and at low lags, the dynamic method appears to be even more reliable.

NBS Scientists

Harry Diamond, Chief of the Bureau's Electronics Division, died suddenly at his Washington home on June 21, 1948. Mr. Diamond joined the staff of the National Bureau of Standards as a radio engineer in 1927, and his scientific achievements led to rapid advancement. In 1942 he was asked to form a new division within the National Bureau of Standards, primarily for research and development on electronic ordnance, and was named its chief. In this capacity he invented, jointly with his coworkers, the radio proximity fuze for bombs, rockets, and mortar shells, considered the No. 2 secret weapon of World War II. He later became head of the Electronics Division, which now includes a broad program of research and development on electronic devices for Government and industry, in addition to military research.

Mr. Diamond's work was diversified, and included numerous applications of radio in aviation, meteorological observations, and direction finding, as well as other fields of electronics. Following his graduation from the Massachusetts Institute of Technology, he taught for several years at Lehigh University, organizing the University's first course in radio engineering. During that time he took his master's degree in electrical engineering.

Mr. Diamond played a large part in the development at the Bureau of the Instrument Landing System (ILS) and participated in the first completely blind flight and landing of an aircraft in March 1933. His ILS is now operating at many airports, and wide adoption throughout the world is planned. Another development of world-wide importance in which he had a major role is the radiosonde, which automatically collects weather information from the upper atmosphere.

Dr. G. E. F. Lundell, internationally known chemist, has retired from active duty as head of the Chemistry Division, but will remain on the Bureau staff as consultant to the Division. **Dr. Edward Wichers,** formerly assistant chief and head of the section on Reagents and Platinum Metals, has been appointed Division Chief to succeed Dr. Lundell. At the same time **Dr. William Blum,** head of the Electrodeposition Section, was designated assistant chief of the Division.

Dr. Lundell became Division Chief in 1937, and under his leadership the scope of the Division's work was greatly enlarged. He actively sponsored research in new fields of polarographic and spectrochemical analysis, and during the war years vigorously supported the work on the uranium project and the acid process for the production of alumina from clay. The division's contribution to the analysis and purification of graphite, uranium, and related materials made possible the successful operation of the first atomic energy reactor. Dr. Lundell has published scientific papers on methods of chemical analysis for a wide variety of inorganic materials, preparation and use of Standard Samples, the atomic weights of gallium and aluminum, and other subjects.

Dr. Wichers is an authority on chemical analysis and on the chemistry of the platinum metals and the rare earths. He has also directed research on the preparation of pure chemical compounds and has been active in the field of standards and specifications for reagent chemicals. Dr. Wichers has been a member of the Bureau staff since 1917, and assistant chief of the Chemistry Division since 1942.

Dr. Blum, who joined the Bureau staff in 1909, has been engaged principally in the fields of electrochemistry and electrodeposition, including electrotyping, electroplating, and electroforming. He has also done work on the atomic weight of cadmium and on the complex inorganic acids.

NBS Publications

Periodicals [5]

Journal of Research of the National Bureau of Standards, volume **41**, number 1, July 1948. (RP1896 to RP1905 inclusive.)

Technical News Bulletin, volume **32**, number 7, July 1948. 10 cents.

CRPL–D47. Basic Radio Propagation Predictions for October 1948. Three months in advance. Issued July 1948. 10 cents.

Nonperiodicals

Research Papers [5] [6]

RP1887. Resin bonding and strength development in offset papers. Charles G. Weber, Merle B. Shaw, Martin J. O'Leary, and Joshua K. Missimer. 10 cents.

RP1888. Metastable transitions in mass spectra of fifty-six hydrocarbons. Evelyn G. Bloom, Fred L. Mohler, Jonathan H. Lengel, and C. Edward Wise. 10 cents.

RP1889. Determination of small amounts of oxygen in organic compounds. William W. Walton, Francis W. McCulloch, and W. Harold Smith. 10 cents.

RP1890. Infrared emission spectra of flames. Earle K. Plyler and Curtis J. Humphreys. 10 cents.

RP1891. Pressure-volume-temperature data for oxygen. Cyril H. Meyers. 10 cents.

RP1892. Reduction of sphero-chromatic aberration in catadioptric systems. Robert E. Stephens. 5 cents.

RP1893. Some energy relations in the systems $PbO–B_2O_3$ and $PbO–SiO_2$. Leo Shartsis and Edwin S. Newman. 10 cents.

RP1894. Divided flow, low-temperature humidity test apparatus. Arnold Wexler. 10 cents.

RP1895. Gradual damping of solitary waves. Garbis H. Keulegan. 10 cents.

Building Materials and Structures Reports [5]

BMS111. Performance of a coal-fired boiler converted to oil. Richard S. Dill and Paul R. Achenbach. 15 cents.

Articles by Bureau Staff Members in Outside Publications [7]

Experimental production of cancer of the skin by ultraviolet radiation. W. W. Coblentz. J. Am. Med. Assoc. (535 North Dearborn Street, Chicago 10, Ill.) **136,** 1040 (April 1948).

Standards on photographic lenses to aid in purchase and use. Irvine C. Gardner. Ind. Standardization (American Standards Association, 70 East Forty-fifth Street, New York, N. Y.) **19,** 43 (May–June 1948).

Changes in the indices of refraction and liquidus of a barium crown glass produced by the partial substitution of some oxides. Edgar H. Hamilton, Oscar H. Grauer, Zeno Zabawsky, and C. H. Hahner. J. Am. Ceram. Soc. (2525 North High Street, Columbus 2, Ohio) **31,** 132 (May 1948).

Performance of the "perfect" book binding. F. T. Carson and C. G. Weber. Library Journal (R. R. Bowker Co., 62 West Forty-fifth Street, New York 19, N. Y.) **73,** 918 (June 1948).

Determination of the product of the constants for the overlapping dissociation of weak acids by electromotive-force methods. Roger G. Bates. J. Am. Chem. Soc. (1155 Sixteenth Street NW., Washington 6, D. C.) **70,** 1579 (1948).

The use of thermocouples in high-velocity gas streams. E. F. Fiock and A. I. Dahl. J. Am. Soc. Naval Engrs. (Navy Building, Constitution Avenue, Sixteenth-Seventeenth Streets, NW., Washington, D. C.) **60,** 139 (1948).

The low temperature heat capacities, enthalpies, and entropies of UF_4 and UF_6. F. G. Brickwedde, H. J. Hoge, and R. B. Scott. J. Chem. Physics (57 East Fifty-fifth Street, New York 22, N. Y.) **16,** 429 (1948).

[5] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $4.50 (foreign $5.50); Technical News Bulletin, $1 (foreign $1.35); Basic Radio Propagation Predictions, $1 (foreign $1.25). Single copy prices of publications are indicated in the lists.

[6] Reprints from June Journal of Research.

[7] These publications are not available from the Government. Requests should be sent direct to the publishers.

Periodicals of the National Bureau of Standards

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